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PRACTICAL IMPLEMENTATION: PHASE LOCK LOOP AND A FEEDBACK LOOP BASED FULL COLOUR LASER TV

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ABSTRACT

In Multimedia society, the needs for large area display are increasing day by day. Many kinds of projection displays are now developed such as LCD, LCOS, DMD and Laser TV. Current Laser scanning projections methodologies is not efficient from cost, weight and power perspective. In this paper we have used low commercial microcontrollers with a scanning mirror (Progressive Scanning) technology. Three laser lights blue, green and red with wavelengths 457 nm, 532 nm and 648 nm are used. Power levels of lasers are adjusted for white color balance. Phase Lock Loop (PLL) with a feedback loop is used to synchronize horizontal (high speed brush-less DC motor) and vertical mirrors (stepper motor) pulses. The resulting Laser TV assembly is more efficient in terms of cost, power and weight.

KEYWORDS

Phase Lock Loop; Voltage Controlled Oscillation; Laser TV, Progressive Scanning.

1. INTRODUCTION

Use of Laser as a light source for Head up Display (HUD) and projection display is increasing day by day [1, 2]. The main advantages of using the laser light for projection displays are come from the original characteristics of laser i.e. high contrast ratio, excellent expression of natural colour and infinite depth of focus. The monochromatic property and colour saturation of the laser light can increase the colour space about four times larger than that of the conventional phosphor system [3, 4]. Laser light is polarized. By using the proper polarized optics, it can yield a higher contrast ratio. The wavelengths of lasers cover more than 92% of all colours which can be perceived by the human eye. With the proper display technology, one can achieve infinite depth of focus because laser has a long coherence length and a low beam divergence. Another advantage of using a laser projection image is that the projected image is no longer limited to a flat screen but it can be projected at any other surface. In spite of these excellent characteristics, Laser TV for commercial application could not realize yet because of laser-related technologies. However, it is evident that we can use the diode laser sources within few years due to the rapid progress of the semiconductor laser technologies. The successful development of compact Laser TV has opened a new area of home application of the laser light.

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The idea of displaying images on a screen is based on the working of the progressive scanning which was initially used in laser printers. The laser assembly for laser printer is shown in Fig. 1 is responsible for printing/drawing pages. The traditional laser scanning assembly includes: a laser, a movable mirror and a lens.

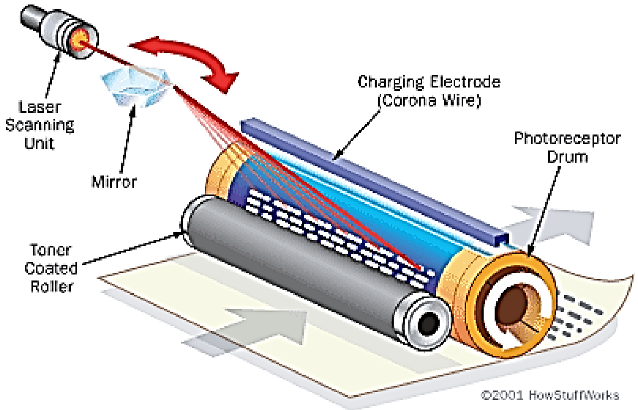

Figure 1: Progressive scanning: Laser printer uses progressive scanning to print pages. A mirror is used to reflect the laser beam. A photoreceptor drum is used to point the next line.

The laser receives the page data -- the tiny dots that make up the text and images -- one horizontal line at a time. As the beam moves across the drum, the laser emits a pulse of light for every dot to be printed, and no pulse for every dot of empty space. The laser doesn't actually move the beam itself. It bounces the beam off a movable mirror instead. As the mirror moves, it shines the beam through a series of lenses. This system compensates for the image distortion caused by the varying distance between the mirror and points along the drum. The laser assembly moves in only one plane, horizontally. After each horizontal scan, the printer moves the photoreceptor drum up a notch so the laser assembly can draw the next line. A small print-engine computer synchronizes all of this perfectly, even at dizzying speeds.

2. RELATED WORK

To increase the quality of the large displays, a diode pumping is used in [5] which sharpen large displays. In [6], author uses a 200 display size image display which is based on the RGB laser to achieve full colour projection. Instead of using three lasers RGB in [7] author uses a single white laser to achieve the full colour laser based projection image. Same technology is used in [8]. Author uses Kr-Ar laser (white laser) beam and the full colour image projection is based on scanning technology. In [9], author uses an antireflective coating on TeO2 crystal for the high power acousto-optic modulator. Same technology is extended in [11]. In [10], Micro Electro Mechanical System (MEMS) based laser projection display is used. Milli-scale mirror actuator with bulk micro-machined vertical combs is presented in [12].An adaptive welder with laser TV-scanner is presented in [13]. In [14] author presented a linear actuation of silicon scanning mirror for laser display. Quantifying head-up display (HUD) pedestrian detection benefits for older drivers is presented in [16]. Similar technology is extended in [15]. In [17], author presented a colour holographic laser projection technology for heads-up and instrument cluster displays. Real-time binary hologram generation for high-quality video projection applications is presented in [18]. Monochromatic green laser is used in [19] to meet mobile projection requirements. Similar technology is extended in [20, 21]. Frequency acquisition rate control in phase lock loop circuits is presented in [22]. In [23], author presented a Laser TV with newly developed laser light sources, but this work doesn’t base on progressive scanning technology.

3. PROBLEM STATEMENT

The design methodology of current Laser TV is based on the roster scanning which heavily rely on the modulation of the laser beam. As a result the beam quality is very low and it's not easy to focus the laser beam for acquiring the designed value. To use the scanning mirror for laser display, the size of the scanning mirror must be larger than that of the laser beam. Also the laser beam must be scanned linearly with analogue operation to make a visible image without distortion. To control the scanning mirror of such large size, the large driving force is also required, due to which the overall size, cost of the Laser TV increases. In this paper, we have proposed a novel methodology (based on progressive scanning) for designing a Laser TV which is based on the low power commercial devices. The resulting system is more efficient in terms of cost, size and power.

4. METHODOLOGY

The laser assembly moves in only one plane, horizontally. The laser beam reflected by the mirror moving horizontally is reflected by another mirror, mounted on a stepper motor [23], moving vertically. After each horizontal scan, the stepper motor takes one step down so the laser assembly can draw the next line. In other words, a mirror is attached on the drum that reflects the laser beam to form images on a surface. We form this screen at such rate (25 frames per second) that it appears a stationary image to human eye. The technique we are using to display images is progressive scanning. Fig. 1 shows the block diagram of the system. We have used phase locked loops and microcontrollers to synchronize horizontal motor (displaying pixels in line) and vertical stepper motor (micro-step driver) for next line alignment.

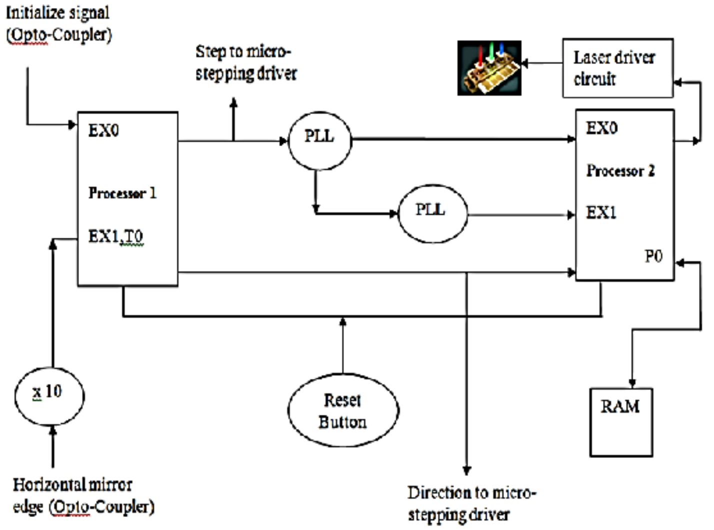

Figure 2: Phase Lock Loop with a feedback loop is used to synchronize horizontal and vertical steps.

5. PRE-PROCESSING

When the system is powered on, pre-processing takes place. In this step, Processor1 moves the mirror (vertical mirror) mounted on the stepper motor to its initial position. While Processor1 is initializing the vertical mirror, Processor2 writes the image in RAM. After completing their tasks, both microcontrollers wait for signals to continue. At this point, the decagonal horizontal mirror, mounted on DC motor is freely moving while the vertical mirror is stationary. Drawing of frames starts when both processors receive continue signals. We have assigned 32 rows to our screen. After the vertical mirror is aligned to its initial position, we move the stepper motor 32 steps clockwise and anti-clockwise alternatively. To view the screen at a reasonable distance we have to cover these 32 steps in less than10˚. In other words the span of the vertical mirror has to be very short and precise. Here we have to make sure that each line is always formed at the same distinct location. To achieve such precision, we have used a micro-stepping driver. We have selected 1600 steps per 360˚. Now the span of our vertical mirror (mounted on stepper motor) is 7.2˚ where each step covers 0.225˚.

Processor1 controls the direction of the vertical mirror. This information is used by Processor2 to read appropriate lines (bytes) from RAM. Also Processor1 is providing the End of Line (EOL) signal to Processor2 i.e. step of the vertical mirror. Printing lines is done by Processor2 based on the input provided by Processor1. Processor2 receives 2 variations of step pulses. One is step x 2, as each line comprises of 2 bytes. We read a byte against this pulse based on direction. Second signal is step x 16. We read corresponding bit in the line. A complete cycle of 32 steps (lines) draws a frame. We repeat this at a high rate (25 fps) to get a static image. Once the pre-processing is complete, frames are drawn in an infinite loop until the power is switched off. Fig. 3 shows the sequence of steps taken to display images.

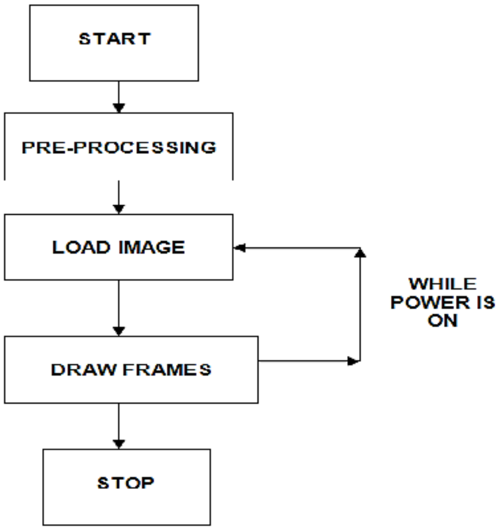

Figure 3: Block diagram of progressive scanning based Laser TV.

6. IMPLEMENTATION

Fig. 4 shows the architecture diagram of laser TV. When the system is switched on, the opto-coupler generates pulses on every edge of the mirror mounted on DC motor. These pulses are used to drive the stepper motor. At the same time these pulses are also sent to the counter which generates sequential addresses for the memory. The bits stored in memory either 1 or 0 determines whether to switch the light on or off respectively.

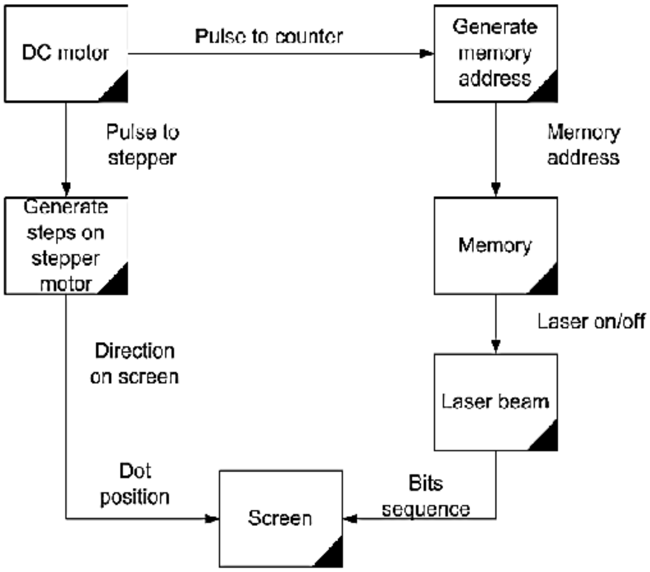

Figure 4: Architecture diagram of Laser TV.

7. ZERO-POINT OF VERTICAL MIRROR

This is the point of the vertical mirror at which the first dot of the image will be printed on the screen or in other words the first line of the image will start from the top left corner of the screen. The position of this zero-point is achieved using an opto-coupler. When the system is switched on, the vertical mirror starts moving to the required location (where the first line can be displayed). As soon as it reaches to the exact start of the line, the opto-coupler attached with the mirror immediately generates a pulse which then indicates to the Processor 1 (as detailed) to take an appropriate step.

An opto-coupler Fig. 5 is a combination of a light source and a photosensitive detector. In the opto-coupler, or photon coupled pair, the coupling is achieved by light being generated on one side of a transparent insulating gap and being detected on the other side of the gap without an electrical connection between the two sides (except for a minor amount of coupling capacitance) as shown below:

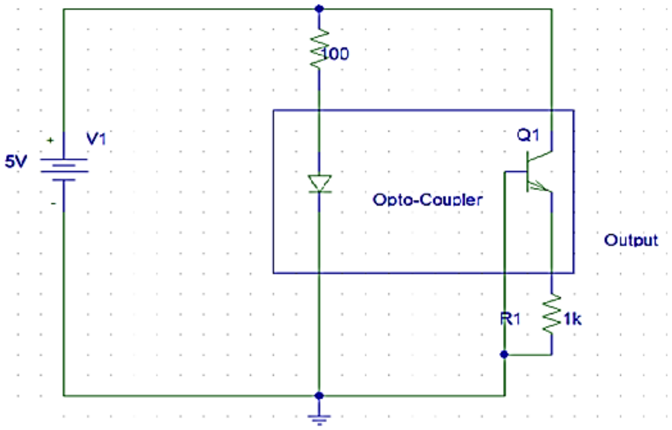

Figure 5: Opto-coupler tuning and resister R1 value setting.

The output of the opto-coupler is between 0 to 3 volts. In order to send a pulse to the micro-controller the amplitude of this pulse must be between 0 to 5 volts Fig. 6. Therefore to obtain this amplitude a comparator (74LS339) is used. The reference voltage is set to 0Volts. If the input voltage increases from reference voltage, the comparator clips to the positive peak i:e +15V. And if the input voltage falls below the reference voltage, the comparator clips to the negative peak i:e 0V. The values can be calculated by using the following formulae.

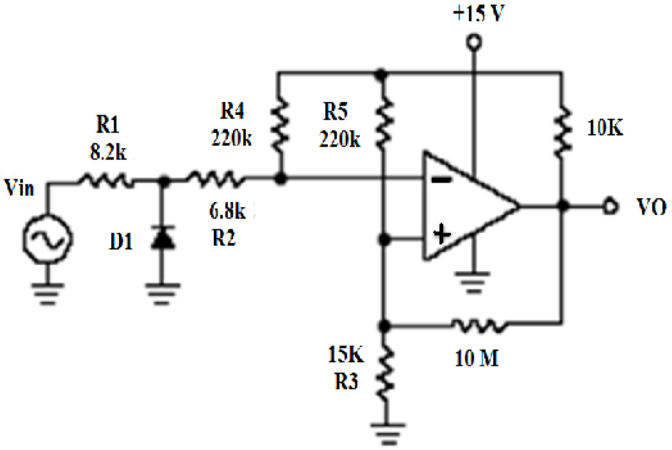

Figure 6:D1 prevents input from going negative by more than 0.6V. R1 + R2 = R3. R3≤ R5/10 for small error in zero crossing.

8. ROTATION OF HORIZONTAL AND VERTICAL MIRRORS

Once the pre-processing is complete and the dc motor attains its maximum speed, the opto-coupler placed on one side of the dc motor generates a pulse on every edge of the horizontal mirror. The horizontal mirror has 10 sides and in completing one rotation of the mirror 10 pulses are generated using a PLL and multiplier circuit. The frequency of the dc motor is 80 HZ. When this frequency becomes the input for the PLL circuit, the divider of 10 in the feedback loop Fig. 2 multiplies each pulse by 10 and 800 Hz frequency at the output. Fig. 7 shows the values of all the resistors and capacitors used to lock the frequency in the range of 800 Hz.

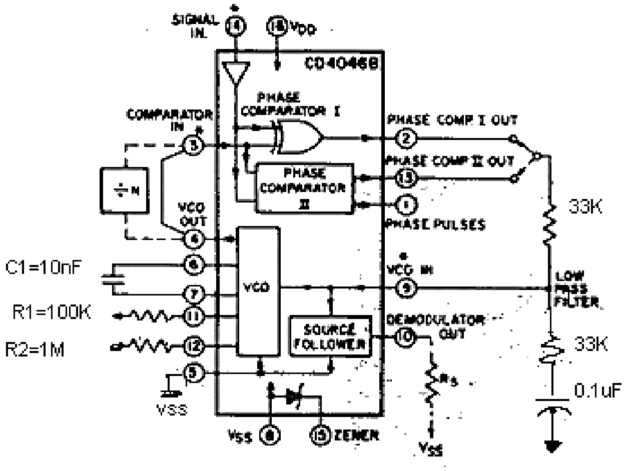

Figure 7: PLL lock range caculation using CD40468 datasheet, R1 = 100K, R2 = 1M and C1 = 10nF.

Fig. 8 shows the lock range of PLL. Here for VDD = 5V, fmin=130 Hz (R2 = 1M and C = 10 nF) and f0 = 900 Hz (R1 = 100 k and C = 10 nF). The lock range is from 130 Hz to 1700 Hz.

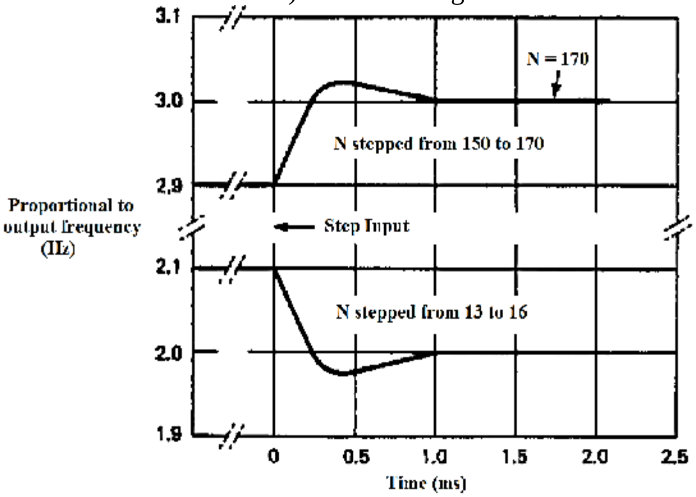

Figure 8: Lock Range of Phase Lock Loop.

The purpose of this dividing circuit is to generate required pulses in response to each input pulse. In our case we need a multiplier of 10 means that we want to generate 10 pulses in response to 1 input pulse. To make the idea clearer as we are using a ten sided mirror and we have placed a pulse generator at only one of the face of the mirror. As soon as this point reaches, this circuit generates ten equally spaced pulses to the output circuit. This divider is basically a counter designed on GAL 22V10.

As a second order low pass filter is more stable than a first order low pass filter, so the VCO design of the second order low pass filter is given in Fig. 9. It consists of a 0.1uF capacitor and two resisters of 33K.

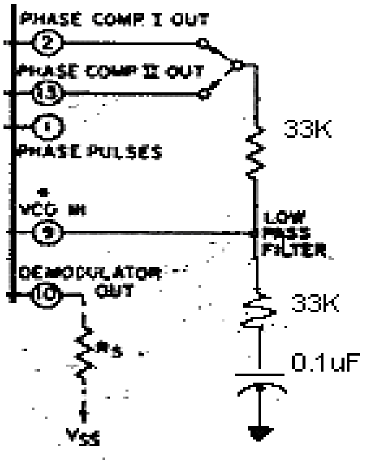

Figure 9: VCO design using second order low pass filter using datasheet R1 = 33K and C1 = 0.1uf.

Fig. 10 shows the complete circuitry of PLL and divider of 10 to obtain the required lock range.

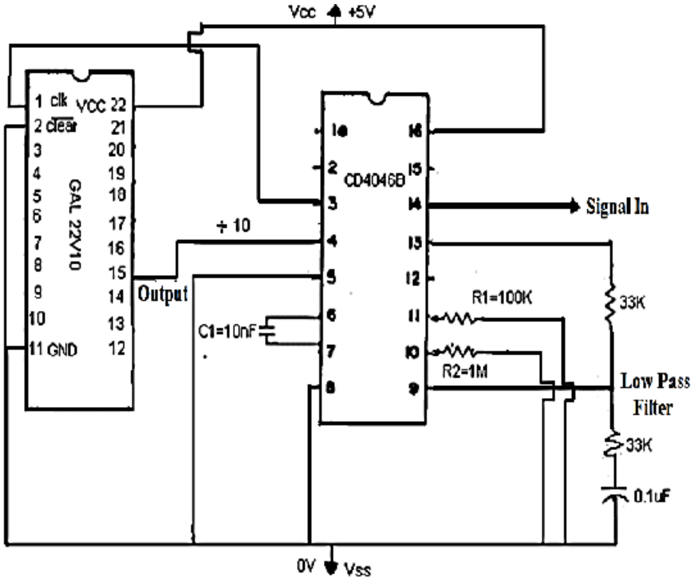

Figure 10: Circuit diagram of Phase Lock Loop PLL and divider of 10 chip.

Processor1 is an 8051 microcontroller (AT89c52). When this processor is powered on, the first task it performs is to bring the stepper motor to its initial position. This is done using EX0 (external interrupt 0) which is configured to generate an interrupt on the falling-edge of INT0 (P3.2). The microcontroller keeps on generating stepper motor steps until the motor is marked as aligned. When the motor is aligned to its initial position, the opto-coupler attached to the stepper motor generates an interrupt (1 to 0 transitions). As a result, we are in EX0 ISR (Interrupt Service Routine). Here we mark the motor as aligned. Now, we wait for the continue signal to proceed. After receiving the continue signal, we configure the microcontroller to receive an input signal which is the edges of the decagonal mirror generated by the opto-coupler attached to it. Here INT1 (external interrupt 0) and T0 (Timer0 in count mode) receive this signal. When there is an edge (1 to 0 transition) on INT1 (3.3), we produce a pulse using Timer1 to give step signal to micro-stepping drive and Processor2. Timer0 is configured in count mode. It generates an interrupt after every 32 edges (1 to 0 transitions) on T0 (3.4). In Timer0 ISR, we invert the direction of the stepper motor. In short, Processor1 is passing edges on horizontal mirrors as steps to stepper motor and inverting direction every 32 steps as our screen consists of 32 lines. As the size of the screen is 16 x 32 lines = 64 bytes, therefore 64 addresses are to be generated to read the image from the RAM because each address contains 8 bits or 1 byte of image.

There are two multiplier circuits which generates pulses on each pulse of the dc motor (on each face of the mirror). The first Multiplier is of 2, which reads 2 bytes of memory. The reason for 8 bytes is because the size of the line is 2 x 8 = 16 bits or 2 bytes. The following circuit of PLL and dividing by 2 generates 2 synchronous pulses in response to 1 input pulse from dc motor. The frequency of the dc motor after getting it from PLL circuit is 800 Hz. When this frequency becomes input for another PLL circuit the output becomes 1600 Hz. Here for VDD = 5V, fmin= 130 Hz (R2 = 1M and C = 10 nF) and f0 = 900 Hz (R1 = 100 k and C = 10 nF). The lock range is from 130 Hz to 1700 Hz.

9. MEMORY INTERFACING WITH 8051

The Intel 8051 uses separate memory address spaces for data and program code. Data or code address space is limited to 64K, hence, addressable with 16 bits through ports P0 (LSBs) and P2

(MSBs). A separate signal, called PSEN (program strobe enable), is used to distinguish between data/code. For the most part, the I8051 generates all of the necessary signals to perform memory I/O, however, since port P0 is used for both LSB address bits and data flow into and out of the RAM an 8-bit latch is required to perform the necessary multiplexing. The following timing diagram illustrates a memory read operation. Memory write operation is performed in a similar fashion with data flow reversed and RD (read) replaced with WR (write). Memory read operation proceeds as follows. The micro-controller places the source address, i.e., the memory location to be read, on ports P2 and P0. P2, holding the 8-MSB bits of the address, retains its value throughout the read operation. P1, holding the 8-LSB bits of the address is stored inside an 8-bit latch. The ALE signal (address latch enable), is used to trigger the latching of port P0. Now, the microcontroller asserts high impedance on P0 to allow the memory device to drive it with the requested data. The memory device outputs valid data as long as the RD signal is asserted. Meanwhile, the micro-controller reads the data and de-asserts its control and port signals. Fig. 11 gives the interface schematic.

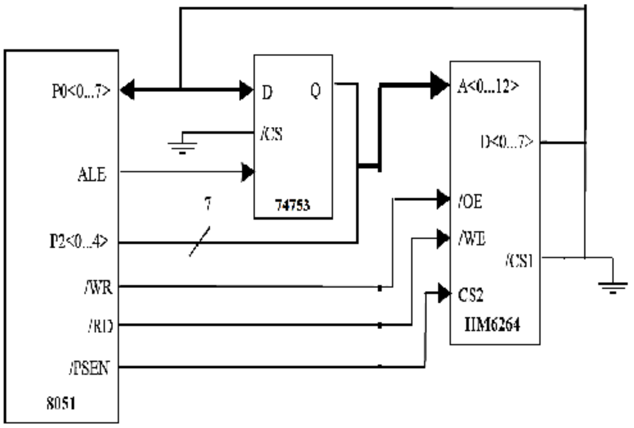

Figure 11: Memory interface circuitry with 8051 micro controller.

10. FUNCTION OF PROCESSOR 2

Processor2 is also an 8051 microcontroller (AT89c52). The first task it performs is to write image in RAM. This image is displayed on the screen. Now, the microcontroller is configured to receive inputs. Both the external interrupts EX0 and EX1 are configured to generate an interrupt on the falling-edge of INT0 (P3.2) and INT1 (P3.3) respectively. Now, we wait for the continue signal to proceed. After receiving the continue signal we enable interrupts. When we are in EX0 ISR (Interrupt Service Routine), as a result of (1 to 0 transition) on INT0, we read a byte in R1 from address in R0. Depending on the direction signal, we decide the address of next byte to read in R0. We are using bank0 here. When we are in EX1 ISR as a result of (1 to 0 transition) on INT1, we switch laser on/off depending on the least significant bit (LSB) of value in R1 and right shift R1 by 1 bit. Processor2 is turning laser on/off in response to the edges of the horizontal mirror.

11. EXPERIMENTAL SETUP

The purpose of this experiment is to investigate the validity of the concept. For this an image is stored in the external memory attached with Processor-2. This image will be read by the Processor-2 from the external RAM. VDD is set to 5V, fmin is set to130 Hz with (R2 = 1M and C = 10 nF) and f0 = 900 Hz with (R1 = 100 k and C = 10 nF). The lock range is kept between 130 Hz to 1700 Hz. Mirror is aligned in such a way that laser beam is reflected at the starting point on the projected display. For vertical stepper motor, 200 steps are configured. Initially, display is set to 200 lines per frame, refresh rate is set to 25 frames per second. Finally, the display size is increased gradually until the image becomes sharpen.

12. RESULTS

Fig. 12 shows the results of experiment. When display is set to 200 lines per frame the picture looks more pixelized and blur as shown in the left side. However by increasing the number of pixels from 200 to 400 on the same screen and by increasing the display to 400 lines per frame, image looks sharpen as shown on the right side.

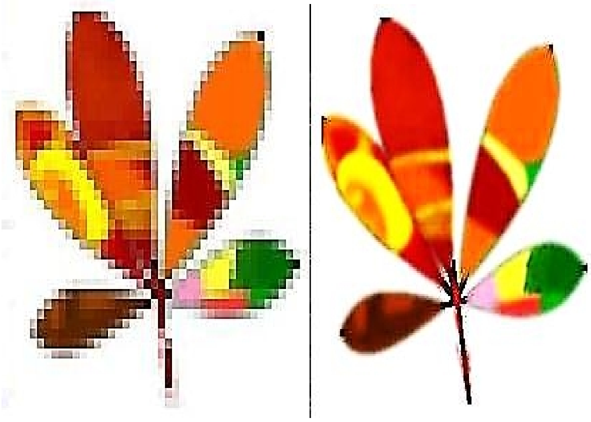

Figure 12: Left side image is quite blur and pixelized. However, by increasing the display size from 200 to 400 lines per frame the image sharpens (right side image).

Fig. 13 shows the variation of voltage input across the PLL capacitor at various temperatures, as the frequency increases from 1.0M HZ gradually.

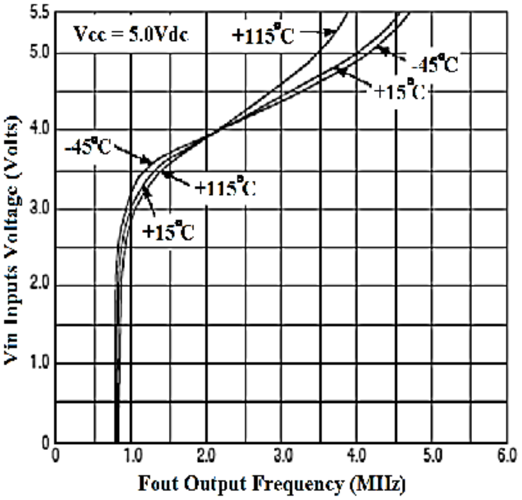

Figure 13: Voltage variation across VCO capacitor at various temperature values.

13. CONCLUSION AND FUTURE WORK

While working on this project, our primary objective was to prove the concept that such a system can be setup to display images. The current system is a reduced version of what we had planned at the beginning. We had planned to make a screen of 200 x 200 pixels. Currently, our dot clock is 12.8 kHz for a screen of 32 x 16 pixels and refresh rate of 25 fps. We have 78 µs processing time for each pixel and we are consuming less than 50 µs. The maximum capacity of our motor is 800 lines/sec approx.

Larger screens require more speed in terms of processing and motors. Let us consider the screen size of 200 x 200 pixels. For a refresh rate of 25 fps, our dot clock has to be 1 MHz (refresh rate x dots/frame). This dot clock frequency cannot be handled with the microcontroller (8051) we are using.
We are displaying 200 lines per frame. For a refresh rate of 25 fps, we need 5000 lines/sec. If we use the same decagonal mirror, we require a motor with speed 30000 rpm (500 rev. per sec) when the mirror is mounted on it. This might seem no big deal. However, it is really important that the mirror must be perfectly balanced. An unbalanced mirror moving at such a high speed can cause severe damage to people and equipment around it. Also, the stepper motor must be able to move 5000 steps/sec. Having done all this, there is still a catch.

Now, our hardware is almost complete for this screen size except for two things. First, opto-coupler will neither work nor it is recommended with a motor at such a high speed due to its poor accuracy. It is recommended to use a photodiode as End-of-Line sensor or a rotary encoder. Sensing the edges of the horizontal mirror accurately is very important as this signal drives the complete system. Second, we need a high speed switching circuit for laser that can switch at frequencies exceeding 1 MHz.

So, these are the few areas which can be explored to make larger and stable images. One thing that must be kept in mind is that if any part of the system is unstable, we cannot get expected results.

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